NPS-LM-06-009

ACQUISITION RESEARCH
SPONSORED REPORT SERIES

What Is the Right RFID for Your Process?

30 January 2006

by

Dr. Uday M. Apte, Professor
Dr. Nicholas Dew, Assistant Professor
Dr. Geraldo Ferrer, Associate Professor

Prepared for: PEO IWS and
Naval Postgraduate School, Monterey, California 93943

Report Documentation Page

Form Approved
OMB No. 0704-0188

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

1. REPORT DATE **30 JAN 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **What Is the Right RFID for Your Process?**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Postgraduate School,Graduate School of Business and Public Policy,555 Dyer Road, Room 332,Monterey,CA,93943**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT **see report**		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**77**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The research presented in this report was supported by the Acquisition Chair of the Graduate School of Business & Public Policy at the Naval Postgraduate School.

To request Defense Acquisition Research or to become a research sponsor, please contact:

NPS Acquisition Research Program
Attn: James B. Greene, RADM, USN, (Ret)
Acquisition Chair
Graduate School of Business and Public Policy
Naval Postgraduate School
555 Dyer Road, Room 332
Monterey, CA 93943-5103
Tel: (831) 656-2092
Fax: (831) 656-2253
e-mail: jbgreene@nps.edu

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.nps.navy.mil/gsbpp/acqn/publications

Abstract

Radio Frequency Identification (RFID) has several applications in both military and civilian organizations. Numerous configurations are possible, and multiple new applications are envisioned in the near future. This paper uses the case method to study several RFID applications in multiple industries and to evaluate how this technology can be used to strengthen the process capabilities of an organization. The goals of this paper are to introduce RFID technology to a manager that is contemplating its adoption and to introduce conceptual frameworks that a manager can use to select and justify the right technology configuration among multiple alternatives.

Keywords: RFID; Operations Strategy; Technology Management; RFID Case Studies

THIS PAGE INTENTIONALLY LEFT BLANK

Acknowledgements

Sincere thanks goes to RADM Jim Greene, USN (Ret), the NPS Acquisition Research Chair for securing the sponsor funding for this research. We would also like to acknowledge Keith Snider and the efforts of the Acquisition Research Program as a whole.

THIS PAGE INTENTIONALLY LEFT BLANK

About the Authors

Uday Apte is Professor of Operations Management at the Graduate School of Business and Public Policy, Naval Postgraduate School, Monterey, CA. Before joining NPS, Uday taught at the Wharton School, University of Pennsylvania, Philadelphia, and at the Cox School of Business, Southern Methodist University, Dallas. He is experienced in teaching a range of operations management and management science courses in the Executive and Full-time MBA programs.

Areas of Uday's research interests include managing service operations, supply chain management, technology management, and globalization of information-intensive services. He has published over 30 articles, five of which have won awards from professional societies. His research articles have been published in prestigious journals including *Management Science, Journal of Operations Management, Decision Sciences, IIE Transactions, Interfaces,* and *MIS Quarterly.* He has co-authored one book, *Manufacturing Automation* and has completed work on another co-authored book, *Managing in the Information Economy*.

Uday holds Ph.D. in Decision Sciences from the Wharton School, University of Pennsylvania. His earlier academic background includes MBA from the Asian Institute of Management, Manila, Philippines, and Bachelor of Technology from the Indian Institute of Technology, Bombay, India.

Prior to joining academia, Uday managed information technology and operations functions in commercial banking, insurance and utility industries for over ten years. He has also consulted with several major US corporations and international organizations including IBM, Texas Instruments, Nokia, Kinko's, Nationwide Insurance, Nations Bank and The World Bank.

Nick Dew is an assistant professor in the Graduate School of Business and Public Policy at the Naval Postgraduate School, Monterey, CA. Nick has a Ph.D. in management from the University of Virginia, and an MBA from the Darden Business School, as well as a BA in history from the University of York in the U.K. Before joining academia, Nick worked in strategic management and sales & marketing for British Petroleum, Europe's largest company, including a two year assignment in BP headquarters and a three-year international assignment in Southeast Asia.

Nick joined the faculty at the Naval Postgraduate School in 2003 where he teaches strategic management in the MBA program. He researches the evolution of the RFID (radio frequency identification) industry and entrepreneurial decision making. His work has appeared in the *Journal of Evolutionary Economics*, the *Journal of Business Venturing,* the *International Journal of Entrepreneurship and Innovation* and the *Scandanavian Journal of Management*. For more information on entrepreneurial decision making, go to www.effectuation.org

Geraldo Ferrer is an Associate Professor of Operations Management at the Naval Postgraduate School. Prior to joining NPS, he was in the faculty of the Kenan-Flagler Business School at the University of North Carolina for seven years. His areas of expertise include global operations, supply chain management, sustainable technologies, product stewardship, reverse logistics and remanufacturing. He has also studied the reverse logistics required in recycling and remanufacturing operations, and inventory problems affecting products made in small batches for frequent deliveries.

He has published on these topics in *European Management Journal, Management Science, Naval Research Logistics, IIE Transactions, Production and Operations Management, European Journal of Operational Research, International Journal of Production Economics, Ecological Economics, Business Horizons* and *Resources Conservation and Recycling*. He is a contributor in the *Handbook of Environmentally Conscious Manufacturing* and *Handbook of Industrial Ecology*.

He has presented his research in national and international conferences in four continents, and in invited seminars in various academic institutions. Dr. Ferrer serves as reviewer in many academic journals and for the Social Sciences and Humanities Council of Canada. He has also reviewed textbooks in the areas of operations management, inventory management and project management. He has consulted for companies in the United States on waste reduction and reverse logistics issues.

He received his PhD in Technology Management from INSEAD, his MBA from Dartmouth College, a mechanical engineering degree from the Military Institute of Engineering in Rio de Janeiro and a BA in Business Administration from Federal University of Rio de Janeiro.

Dr. Ferrer was founder and director of Superserv Ltd., a company that promoted technology transfer ventures between North American and Brazilian business, introducing innovative technology products for the petroleum industry.

THIS PAGE INTENTIONALLY LEFT BLANK

ACQUISITION RESEARCH
SPONSORED REPORT SERIES

What Is the Right RFID for Your Process?

30 January 2006

by

Dr. Uday M. Apte, Professor
Dr. Nicholas Dew, Assistant Professor
Dr. Geraldo Ferrer, Associate Professor

Prepared for: PEO IWS and
Naval Postgraduate School, Monterey, California 93943

THIS PAGE INTENTIONALLY LEFT BLANK

Table of Contents

THIS PAGE INTENTIONALLY LEFT BLANK

Executive Summary

Radio Frequency Identification (RFID) has several applications in both military and civilian organizations. Numerous configurations are possible, and multiple new applications are envisioned in the near future. This paper uses the case method to study several RFID applications in multiple industries and to evaluate how this technology can be used to strengthen the process capabilities of an organization. The goals of this paper are to introduce RFID technology to a manager that is contemplating its adoption and to introduce conceptual frameworks that a manager can use to select and justify the right technology configuration among multiple alternatives.

THIS PAGE INTENTIONALLY LEFT BLANK

I. Introduction

The evolution and application of new technologies has always played a key role in improving the operational performance of production and delivery of goods and services. As a new technology is developed and its potential is proven, firms contemplate using it in processes and equipment that can generate value for their customers while improving their company's operational performance in terms of cost, quality, speed, flexibility and so forth. Many experts assert that Radio Frequency Identification (RFID) is a proven technology innovation that is being adopted by a wide range of organizations and is likely to have a significant impact on the field of operations management in the years to come (Lahiri, 2005; Fleisch & Tellkamp, 2005; Wyld, 2005).

The ability to identify things is one of the most basic, yet important, prerequisites to making and delivering goods and services. Consider, for example, an order fulfillment process. In this process, it is critical that the worker is able to identify and locate a specific item being ordered and then pack and ship it to the customer. As an automatic identification (or auto-ID) technology, RFID can help machines identify things such as physical objects, animals or customers and, consequently, dramatically simplify the operational processes. In addition, RFID technology has the ability to store and exchange large amounts of information about objects in the system. RFID technology can, therefore, be used as a sophisticated data-gathering platform to support and enhance the decision and control capabilities in computer-integrated manufacturing and service operations; that is the main attraction of this technological innovation.

Although the use of radio frequency to identify goods is not a new concept, only in recent years are firms starting to realize the true potential of RFID. Current applications provide benefits as varied as reduced cost and cycle time, and improved process speed, dependability and quality assurance. For example, recent concerns with supply-chain efficiency at the US Department of Defense (DoD) and at major retailers such as Wal-Mart, Tesco and others has prompted these organizations to adopt RFID technology. Moreover, RFID's ability to individually identify items in the supply chain has made it possible for the government to use this technology as a powerful security tool in many settings—ranging from border protection to livestock control.

Currently, the RFID technology is evolving at a very fast pace, leaving room for speculation regarding the benefits that RFID investments may or may not provide. Meanwhile, managers continue to struggle with the decision to adopt this technology, trying to select the configuration that is most appropriate for their operational needs and that enhances their organization's operational performance. In planning for the introduction of RFID, a manager must deal with four major technology management issues (Cohen & Apte, 1997): selection, justification, implementation and coordination. In this paper, we primarily deal with the first two issues in technology management—selection and justification—that are critical for managers to understand when contemplating an investment in RFID technology.

First, the issue of technology *selection*: In adopting a new technology, a manager is confronted with a range of choices affecting the design of the operational processes and the competitive position of the products and services being produced and sold. A manager addresses such technology selection issues as: What are the choices? How should alternatives be evaluated? How should a choice be made? What are the criteria for selecting a technology? The design of RFID systems requires that numerous parameters specifying the technology should be selected so as to provide suitable operational capabilities to the system.

The second major technology management issue is *justification*. Automation technologies require major investments of capital, attention and enthusiasm. Such investments must ultimately prove to be worthwhile in terms of their costs and benefits. In all firms, a justification process is required prior to investment in a technology, and an evaluation process is needed during and after its implementation. In technology justification, several issues confront the manager:

How should the analyses in justifying a technology be applied? Are traditional financial criteria and analytical approaches relevant; do they serve as barriers to technology adoption, or is there a need to develop and use new analytical approaches?

To set the stage for addressing the issue of selection, we introduce the range of choices available in configuring the RFID system. We discuss a variety of tag types (passive, active or semi-passive), possible operating frequencies, and the types of readers. We also discuss alternate system architectures (such as closed and open networks) and how they affect the economics of the RFID investment. The discussion of technology choices is made at a level appropriate for an informed managerial decision.

To better understand the RFID configurations that have been used in practice in a wide range of situations, we discuss and analyze several current applications of RFID technology. Most of these applications have been studied using primary sources of information such as personal interviews with buyers and suppliers of RFID systems. In these case studies, we focus on the operational needs satisfied by RFID technology and on the benefits realized in terms of four major process capabilities of an operation: quality, speed, flexibility and cost. Finally, we build on the analysis of RFID applications and propose conceptual frameworks that managers can use to select the right configuration for their RFID systems.

Next, we deal with the issue of technology justification. The benefits and costs associated with RFID technology use are identified, and the challenges associated with estimating them are discussed. We then review the traditional justification tools, such as net-present value and payback period calculations, and conclude that the approach of real options is better suited for justifying RFID technology than traditional methods.

The paper is organized as follows: the next section discusses some of the research literature that is related to RFID adoption. Section III introduces salient features of RFID technology, in particular the differences and capabilities of different types of tags, readers, and network configurations. Section IV presents cases of RFID adoption, starting with civilian examples, followed by applications of special interest to the military forces. Sections V and VI, respectively, deal with technology selection and justification. The two sections present the results of our case analysis and the proposed conceptual frameworks that can help managers select and justify the right configuration for their RFID systems. Section VII concludes the paper with a summary of findings along with a brief discussion of the possible directions for future research.

II. Literature Review

RFID technology was developed over several decades, as reviewed in the works of Landt (2001), Lahiri (2005) and Dew (2006). There are several bodies of research that are particularly relevant to the adoption of RFID technology. The first focuses on the role played by organizational resources, skills, knowledge, capabilities and learning (Levitt et al., 1988; Nelson & Winter, 1982). The adoption of an innovation can require organizations to either currently possess or to implement complementary organizational skills and capabilities so they can take advantage of the innovation (Argote & Ingram, 2000). For example, just as the diffusion of typewriters depended on the diffusion of typing skills, the diffusion of manufacturing innovations depends on the availability of relevant skills among adopters (David, 1985; Szulanski, 1996). In such cases, payoffs to adoption of an innovation are organization-specific because they depend on each particular organization's skills and capabilities in utilizing the innovation. Yet, the relevant organizational skills are costly to acquire. One reason is that information and knowledge are "sticky," and, therefore, costly to transfer between organizations (Von Hippel, 1994). Another reason is that the transfer of knowledge within or between organizations is dependent on the absorptive capacity (i.e., stock of knowledge) already held by receivers (Cohen & Levinthal, 1989). The difficulties of acquiring the relevant knowledge are further moderated by causal ambiguity (Lippman & Rumelt, 1982; Szulanski & Winter, 2001) and arduous relationships between sources of knowledge and recipients (Szulanski, 1996). Because of the difficulties associated with the replication of relevant knowledge and the spreading of best practices, organizational capabilities can be the source of sustainable profits from adopting innovations (Barney, 1991; Argote & Ingram, 2000). In this context, early adopters of RFID technology have the opportunity to maintain competitive advantage *as long as the correct configuration is selected*, which makes this a crucial decision for many organizations.

Because RFID is a networked technology, its adoption is dependent upon externalities that are typical of communication technologies (Schilling 2002; Suarez 2005; Majumdar & Venkataraman, 1998). The value of products in this category increases with the installed base of users (Rohlfs, 1974). For example, owning the only telephone in a region is not very useful, but as the number of telephone users increases, owning a telephone becomes incrementally more valuable (Artle & Averous, 1973). Research shows that growth of the installed base and complementary product availability are critical drivers of subsequent adoption of a technology (Srinivasan, Lilien, & Rangaswamy, 2004; Gandal, Greestein, & Salant, 1999). After a critical mass of adopters is reached, adoption accelerates. However, "lock-in" to a given technology may occur (Katz & Shapiro, 1985) resulting in what have been described as "winner-take-all" markets (Schilling, 1998 and 2002), i.e. the dominance of single technology, as we have observed with VHS (video cassette standard), Windows (PC operating system), iPod (portable music device) and UPC (barcode standard). This convergence to a single technology occasionally results in a corporate monopoly if early developers do not reach an agreement regarding a technology standard that is available to all. Hence, the diffusion and adoption of RFID will be greatly influenced by the success of standards in development by ISO and other major industry players.

Since Skinner's (1969) seminal article, researchers have developed increasingly complex and robust models of manufacturing strategy to fit within the broader domain of corporate strategy. Wheelwright (1978) identified the manufacturing performance criteria that are critical to contributing to corporate strategy: (cost) efficiency, dependability, quality, and flexibility, that later became known as the competitive capabilities in manufacturing. Ferdows and De Meyer (1990) extended the competitive capability framework indicating the existence of an efficient competitive progression for acquiring these capabilities. They should be acquired in the following order: quality, flexibility, dependability (speed), and, finally, cost. To push the concepts of competitive capabilities further, Teece, Pisano, and Shuen (1997) developed a dynamic capabilities framework for firms facing rapid technological change and development. In such an environment, the firm's competitive advantage resides in speed and adaptability, or, simply speaking, a firm's competitive advantage is its ability to identify and implement new advantages within a rapidly changing competitive environment. New technologies, such as the use of radio frequency identification to manage critical processes, have the potential to provide such advantage, if appropriately implemented.

THIS PAGE INTENTIONALLY LEFT BLANK

III. Radio Frequency Identification Technology

A manager typically counts on expert technical assistance to make detailed tactical decisions about investments in technology. However, decisions related to selection and configuration of technology such as RFID require significant investment and have a strategic impact on the organization. To ensure that the right RFID configuration is selected, the manager must be an informed and intelligent consumer of the technology. Hence, in this section, we introduce and discuss RFID technology from a managerial viewpoint.

RFID is a semiconductor-based technology that can be used to identify or track objects. In its most basic design, an RFID tag can be thought of as a wireless barcode. The system typically includes radio-emitting tags, readers, and a host computer with the appropriate software. A tag is attached to each object being tracked, and it emits a unique electromagnetic signature that is captured by the reader. The host computer processes the respective information as needed. The electromagnetic wave is usually in one of five ranges of the radio frequency spectrum: 125-134 kHz (LF: low frequency), 13.56 MHz (HF: high frequency), 315-433 MHz or 868-915 MHz (UHF: ultra-high frequency), 2.45 GHz or 5.8 GHz (MW: microwave). Individual systems operate at very specific frequencies which depend on allocations made by regional authorities (Lahiri, 2005). Table 1 provides more details regarding these radio frequency ranges, indicating in which media they are transparent or opaque, the typical read rate and the read distance afforded by the range.

Table 1. Applications and Characteristics of Each Tag Frequency

Band	Frequency	RF transparent materials	RF opaque materials	Antenna size	Read rate	Read distance
LF	125-134 kHz	Plastics, fabrics, oils, liquids, wood and some metals.	Dense materials (brick and metals).	Largest	Lowest	Shortest
HF	13.56 MHz			Large	Low	Short
UHF	315-433 MHz			Small	High	Long
	868-915 MHz	Most plastics, fabrics, oils, paper, dry wood.	Dense materials, wet wood, mud or snow.			
MW	2.45 GHz	Most plastics, fabrics, oils, paper.	Dense materials and liquids.	Smallest	Very High	Medium

The reader is a device used to collect the radio frequency signals emitted by the tags and to transfer that information to the network computer. Readers may be fixed or portable and always require an antenna. Selecting and positioning the antenna is a tough engineering task; one must ensure the items are not read more than once and all items are read when expected. A reader receives the individual signal as each tagged object comes within range. It then transmits the information collected to the host computer, which may store it in a database for further processing as needed. Depending on the complexity of the task and the desired reading range, the system may use “passive tags,” “active tags” or “semi-passive tags.” Each of these has different capabilities regarding the amount of information it can exchange and the distance it may be from the reader before communication takes place.

Passive Tags and Readers

Passive tags do not have their own source of energy. Instead, they get their power from the interrogation signal of the reader, which activates each tag for a moment in time when it emits its signature in a process called “modulated backscatter.” Passive tags exchange power and data with the reader. Read ranges and performance characteristics vary depending on several parameters. For instance, LF (low frequency) passive tags perform well around liquids but have the shortest range of all types of tags (often just a few inches). On the other hand, UHF (ultra-high frequency) tags are quickly read and have a longer range (12-20 feet), but the signal may be interrupted by liquids, metals and other dense media such as brick. In addition, passive tags are usually robust and can withstand significant wear and tear. Since they do not use a battery, designing a system where the tag remains functional for an indefinite period of time is conceivable. Moreover, passive tags vary significantly in terms of their memory capacity and read-write capabilities, ranging from simple identification tags to mobile databases containing item history information.

If the purpose of the tag is just identification (as in most supply-chain applications), then a simple passive tag may be used. This type of application would induce the production of very large lots of identical chips, differing just by their unique signature. Each chip would contain just the identification digits, and the reader would have very simple input-output capabilities. For the chip manufacturer, this would ensure economies of scale and significant cost reduction. Ultimately, the low-cost passive tag may be used as a direct substitute for the barcode. However, passive RFID presents a very significant disadvantage: microchips will always cost more than printed stickers (a barcode printed on the product's label is virtually free!). Hence, passive tags may be more useful in applications where functions other than object signature are desired. These applications would use at least one of the major features that passive tags possess and barcodes do not:

- Data capacity—Tags can be developed with the ability to store long signatures, a useful feature if the organization intends to identify individual items and not just the product. This is particularly useful where lot identification or expiration dates need to be controlled, as is the case of pharmaceutical products and other perishable goods. Moreover, data encryption may be incorporated if the tag includes sensitive data about the item.
- Signal ubiquity—Since the data is read using radio frequency, there is no need for unobstructed line-of-sight between the reader and the tag. This capability reduces manual intervention and enables reading information from multiple items

at the same time. Moreover, it enables a reader to access the individual tags in items inside packages and cartons, reducing product handling in warehouses and other storage facilities.

- Read speed—Passive RFID readers can access hundreds of tags per second using algorithms that momentarily switch each tag on, read it, turn it off, and then move to the next tag. Since item identification and counting is often a time-consuming activity in inventory handling processes such as cross docking and shelving, fast read speed may remove bottlenecks in the supply chain.
- Robustness—Inside a simple plastic case, passive tags require no maintenance and may have practically unlimited life expectancy. This is an important feature if the tags are used to identify valuable (or sensitive) assets in the organization. If the tag is appropriately encased, it may last an indefinite amount of time in various environmental conditions, and it may be recycled multiple times.
- Discreetness—In some applications, miniature tags may be attached to the package or inserted in the host asset itself, which may be a particularly useful asset management tool. RFID have been used as a deterrent of cattle theft; a tag inserted in conspicuous areas of the animal will stay in it until the animal is processed in the abattoir.

Whenever an application justifies exploiting one or more of these capabilities, we expect that RFID technology will displace the time-tested barcode.

Active Tags and Readers

For some applications, users may require the ability to send and receive signals from greater distances or to perform functions that require an independent source of energy not available in the passive tag. When this happens, active RFID technologies may provide the solution.

In active RFID systems, the tags and readers exchange only data, not power. The tags incorporate batteries (which have a long life expectancy) as their sole source of energy. Because active tags do not need to scavenge power from a reader, active tag systems use low-power radio waves that generally create less interference with other wireless networks.

Another difference between active and passive systems is the reader-tag interrogation process: the most common active tag, a transmitter, continuously beacons its identity at regular periods (i.e., it remains “active” by sending out a repeated “ping” into the environment), which the reader receives once it comes within range. Battery consumption is an important concern for this type of tag, so it is carefully programmed to ping at time intervals compatible with the application’s needs.

To save battery life, an active tag may have a more efficient design in which it sleeps in the absence of a reader. This tag is a transponder; before the data exchange takes place, it periodically wakes up and pings to check if a reader is listening to it. A transponder may also be designed to remain dormant until a reader sends a signal to activate it. The signal may be encrypted for security reasons or to prevent the tag from being awakened by the “wrong” reader. Therefore, an active tag may remain silent for longer periods of time, saving battery or preventing detection from unwanted sensors—an important security feature.

Active tags sometimes have sensors and storage memory attached to them to record information collected, such as temperature, humidity, vibration, etc. Once the tag is within range, it reports sensor information back to the reader. As features are added, however, tags become physically large, and battery life is compromised. Hence, the manager has to select these features very carefully because they affect key variables that are in permanent trade-off: cost, robustness, longevity, and range. As the designer attempts to improve these variables, the remainder may be adversely affected. For example: to increase range, the designer may select a chip and antenna combination that is more costly, is more cumbersome (thus less robust), and draws more energy from the battery (reducing life expectancy.) To improve robustness, the designer may select stronger enclosure, with requisite increases in cost and form factor, and so forth. Hence, the designer of an RFID system must take a careful look at the needs of the organization to ensure that the tag capabilities balance the trade-offs effectively. In all, active tags are akin to dedicated computers, capable of exploiting many features. Their benefits include:

- Location flexibility—signal strength allows information exchange with the reader at great operating distance.
- Programmability—the tag may incorporate a variety of commands to collect targeted environmental information.

One particular type of active tag is the RTLS (real-time location system), which allows precise location of the asset fitted with the tag (Armanino, 2005). Sensors located in the perimeter of the operating area (indoor or outdoor) sense the tag and communicate the signal strength to a central computer that, by triangulation, calculates its precise location. This capability has been used extensively to individually locate assets within large facilities.

Semi-passive Tags and Readers

Semi-passive tags extend the functionality of passive tags by collecting information using sensors that operate even in the absence of a reader. Consequently, semi-passive tags require a battery. Usually, the sensors in semi-passive tags are used to collect environmental data such as temperature, pressure or humidity. However, other sensors might be installed to track usage patterns of the host asset. The tags are called semi-passive because, despite the battery to feed the sensors, they only transmit information by returning a modulated backscatter signal when activated by the reader as passive tags do, which gives them a similar range of operation. This design allows live monitoring of the environmental conditions in the proximity of a tag, without it spending battery energy to send the signal as active tags do. The amount of data that can be captured depends on its memory capacity, and its lifespan depends on how often it collects information from the surrounding environment and on how quickly the battery life is consumed. Applications using semi-passive tags take advantage of at least one feature that it delivers better than passive or active tags:

- Discreetness—Compact size allows incorporating the tag in the design of the host asset.
- Functionality—Sensors collect and report data on environmental status or usage pattern.
- Security—Tag only transmits identity when interrogated by a reader with suitable encryption.
- Cost effectiveness—Limited functionality allows extensive battery lives and low-cost design.

The choice of tag type is clarified further in Table 2, which allows a first level selection of the appropriate tag according to its strengths and capabilities.

Table 2. Strengths, Limitations and Capabilities of Each Tag Type

Tag type	Strengths	Limitations	Tag capabilities
Passive	Lowest cost, longest life. All frequencies.	ID only, short reading range	Inventory control, supply-chain management, theft deterrent
Semi-passive	Low cost, long life, few sensors. All frequencies.	Limited memory, battery-life dependent	Inventory control, remote control, environmental tracking
Active (general)	Multiple sensors, long memory, long reading range	Expensive, battery life dependent. UHF only.	Asset management and control
Active (RTLS)	Location capability, long memory, long reading range	Expensive, battery-life dependent, dedicated use. Microwave only.	Asset location

RFID Networks

A simple RFID network within a small organization may require a minimal number of readers. However, a large network involving multiple organizations, such as a supply chain, may require a large number of readers located in the premises of multiple organizations. Clearly, a simple RFID network confined within an organization does not have to adopt a universal standard, as long as all readers in the network can receive and interpret the signal emitted by the tags in the system. In practice, as the technology evolves, standards are created to indicate acceptable operating frequencies in all frequency bands such that users have the confidence of making the technology investment without the risk of being locked to a single supplier. Consequently, whether they are closed or open, new RFID networks are built around standardized frequencies and technologies.

The thread that keeps the network together is the *edge system*, which interfaces the readers with the host computer hardware and software. Its main responsibility is to collect the data from the reader and control its behavior. In addition, it filters duplicate reads from multiple readers, aggregates the data and sends it to the host computer. The host computer software interprets the data from the edge system and interfaces with the corporate ERP or another data management program where the data is finally processed (Lahiri, 2005).

An RFID network with closed architecture involves a single organization without the expectation to expand the network to additional players. Closed networks operate within the boundaries of an organization and may use proprietary encryption or data-management technologies. They have been used for many years in different applications, such as managing livestock, tracking work-in-process inventory, managing hospital patients and as theft deterrence. It is also used in general purpose entry-control devices (identification passes, keyless car entry) and automatic payment systems (pay-at-the pump gas stations, road tolls). These applications work well because they do not require open transmission of data or the use of complementary technology by multiple stakeholders.

An RFID network with open architecture adopts universal standards that enable the addition of new players in the network with minimal cost to the organization. The organizations in the open network may have different objectives, each using the data collected in different ways. For example, a seller may use the information to track lot number and delivery date, and a buyer may use the same information to track the expiration date of perishable merchandise.

The presence of technology standards is what characterizes the open network, and is the greatest challenge facing current RFID project designers. Open systems typically require technology standards so that different stakeholders can use compatible technology (i.e., tag and reader compatibility) and internalize network externalities without violating commercial contracts between member organizations and technology providers.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. Case Studies of RFID Applications

The use of RFID technology in business applications is quite recent, and, hence, case research is an appropriate methodology to use in this context. This methodology lends itself well to early, exploratory investigations where the variables are still unknown and the phenomenon not well understood. As argued by Meredith (1998), an emergent phenomenon can be studied in its natural setting with case research, and a meaningful, relevant theory can be generated based on the understanding developed through observing actual practice.

When building theory from case studies, it is possible to select cases using alternate approaches of sampling or replication. (Eisenhardt, 1989; Voss et al., 2002; Yin, 1994). Since the goal of the research at hand is to develop managerial guidelines for choosing RFID technology, we selected the former approach to understand the technology systems used in a wide range of applications. We study 13 RFID cases in total. We conducted focused interviews with users and technology providers of 10 illustrative civilian and military applications to develop a better understanding of the nature of RFID technology. In addition, we collected public data on some of these cases and three other relevant cases to obtain a broader view of the technology's potential.

We coded the case data on a number of dimensions, identifying the operational needs and the performance metrics that were targeted for improvement (such as cost efficiency, quality assurance, cycle time, etc.) in each application. This data was analyzed further in two steps. First, we tried to identify and then determine the correlation between the operational needs, the targeted performance metrics and the configuration adopted. Second, the qualitative case descriptions were reviewed to gain further insights into the choice of RFID system configuration.

In this section, we describe 13 RFID cases with different technology configurations according to the type of tag (active, semi-passive or passive) and the type of network architecture (closed or open). We should mention that to limit the length of this section, we have kept the descriptions of these cases very brief. However, further details on these RFID cases are available from the authors upon request.

Civilian Applications

Passive tag application: Toll tag

The use of RFID tagging for automated toll collection has a long history, dating back to the 1970s (Landt, 2001, 2002). One operational need addressed by RFID here is the need to identify a vehicle and its owner so that appropriate tolls can be charged. The Singapore government launched a novel tagging system in 1998 based on proprietary RFID technology in microwave band to ensure rapid reading of passing vehicles. The system applies tags to vehicles, and readers are installed onto gantries above the highway which identify the date and time when each vehicle passed through the checkpoints for appropriate charges.

While one economic driver of the RFID system in Singapore was the substitution of labor by electronics, another justification for the system was space constraints. As traffic volumes increase, toll road operators need more space for tollbooths, space that often is not physically available. RFID tagging raises the throughput of tollbooths and, therefore, reduces the number of booths required. This makes RFID-equipped toll roads very appropriate in Singapore, where space is limited and very expensive.

The key novelty in Singapore is the way traffic authorities use the system to set variable road prices depending on the time of day. Based on level of traffic congestion expected at a given time, the authorities change road prices up to three times a month in order to alleviate road congestion and lower the social costs of congestion. Based on their experience, Singapore traffic managers have fine-tuned road prices by reducing the number of instances and length of time punitive pricing is used to discourage travel.

Passive tag application: Livestock tag

Major beef exporting countries such as Australia, Brazil, Canada and the United Kingdom are significantly concerned with the risk of "mad cow" and/or foot-and-mouth disease, since outbreaks of these diseases have resulted in a halt of exports and forced decimation of the livestock populations in order to prevent the spread of these diseases across borders. An operational need addressed by a passive RFID tag is to identify individual cattle and trace their movement through the supply chain to the slaughter process. This makes it possible to identify with which other animals cattle might have been in contact with and, thereby, prevent the spread of contagious diseases within these countries' borders.

Australia was the first country to introduce mandatory RFID tagging of all cattle, followed by Canada, which replaced its previous mandate to tag all cattle with barcodes. Similar mandates have been introduced or are in discussion in all major beef-production countries. The National Animal Identification System, currently under discussion in the US, would require tagging virtually all domestic animals raised for human consumption to ensure the identification of the premise that is the most likely source of a contagion within 48 hours (Wyld, 2005). A cattle-control network usually requires individual tagging and the control of entry or exit points in corrals, abattoirs, exhibitions or other locales where the animals might commingle. Low frequency tags must be used because they are the least affected by mud, snow and humidity. However, given the short reading distance, handheld readers are required, which makes the reading process less effective. Accessory benefits of cattle tagging include tracking stock flow in the supply chain and improving stock quality by managing the heredity of prized animals (*RFID Journal*, 2005).

Passive tag application: Railcar tag

For many decades, US railroads have had difficulty dealing with the competition from long haul trucking, which was deregulated in 1980 and thereafter showed significant service improvements. By comparison, railroad service was poor. One observer explains, "They'd lose railroad cars or whole trains" (Landt, 2002). To effectively compete with the trucking industry, the railroads found it essential to identify and locate a railcar to know how it was moving through the system, and to link each railcar with its contents to have access to real-time product and tracking information. To help monitor the location of railcars, the Association of American Railroads implemented RFID technology across North America using 3,000 readers to track 1.5 million railcars and locomotives. The railroad companies agreed on a common standard for the technology and included data-sharing arrangements as part of the implementation.

Benefits of the system included service improvement and cost reductions. For instance, Burlington Northern Santa Fe Corp. eliminated 500 clerks who previously recorded railcar movements manually in a system that was prone to human error. The RFID system reduced these errors, which further reduced costs while improving the service reliability to railroad customers.

Some railroads have expanded the system to include semi-passive RFID tags that monitor critical functions of the locomotive operations, notifying potential breakdown or mechanical emergencies to repair crews, which are ready and waiting for the locomotive by the trackside when it needs repairs. This reduces costs by enabling planned maintenance and minimizing downtime and improves service by reducing unplanned delays.

Semi-passive tag application: Smart tires

Semi-passive RFID tags used for tire management allow tire leasers to identify individual tires and monitor tire operating conditions such as distance run, pressure and temperature at regular intervals. The tags operate in LF to avoid interference from the tire rubber. They have unique IDs, as well as real-time and historical data about the operating history of tires, including:

- Distance run—This helps fleet managers schedule planned maintenance in order to ensure maximum tire life. For the tire owner, this helps the enforcement of tire-leasing contracts.

- Tire pressure—When a tractor-trailer rig rolls into its depot, the tags in each of the 18 tires send information about the tires to a reader located at the entrance of the lot, including data on the internal tires, which are not easily accessible. Fleets with tire maintenance programs manually check the air pressure on every tire about once a week (which manually would take 20 minutes per rig). RFID technology substitutes manual checking, which speeds the process and saves labor.
- Tire temperature—This allows monitoring usage to prevent suboptimal conditions. Hence, it enables lower lifetime tire costs by ensuring that a higher percentage of tires are suitable for retreading. Also, given temperature history, a retreader is able to identify the most appropriate tread for a given casing.

Consequently, smart tires bring a number of benefits to vehicle fleet operators and tire owners. They are easier to manage since RFID helps in the development of fair tire leasing contracts with efficient consumption measures, keeping track of the distance run for correct invoicing. This data tracking reduces the conflicts between supplier and buyer by ensuring that the tires operate at proper parameters.

Semi-passive tag application: Refrigerated trailer tag

Sysco, the largest distributor of temperature-controlled food, is testing a system to identify, locate and track individual trailers as they move through the supply chain, and to monitor and record at regular intervals the temperature conditions inside refrigerated trailers. Upon delivery, the tags are handed to the customer, who can then interrogate them to inspect the temperature log before accepting the shipment (Gilbert, 2005).

The system uses open, standard, EPC-compatible tags so that different players in the supply chain can access the information collected. Because these semi-passive tags use low-power backscatter technology (the same as passive tags), battery life is longer and tag cost is lower than if the tag were active. In addition, the tags are reusable, which reduces the system's operating cost.

There are two key justifications for using this type of tag in the supply chain. First, temperature monitoring supports quality by assuring the customer that the goods were kept at the correct temperature through the supply chain. Ultimately, this also saves costs by providing the ability to detect which party was responsible for losses; this, in turn, reduces the costs of moral hazard and reduces insurance premiums. Second, this type of monitoring ensures the security of product in the supply chain by creating a custody chain that decreases the opportunity for theft or tampering (for instance, by terrorists who might seek to contaminate the food chain).

Active tag application: Vehicle tag in auto assembly plant

According to some market surveys, the automotive industry is the world's largest user of RFID by value, with purchases of $600 million a year (which amounts to half of the RFID market). Automakers have pioneered the use of an RTLS (real-time location system) which uses multiple RFID readers in different locations to triangulate the exact position of active RFID tags. Two applications stand out: locating finished cars in parking lots and managing inventory levels of components used on assembly lines.

In some assembly lines, individual vehicles are identified and tracked as they progress through the assembly line and are placed in parking lots. A reusable active tag is hung on the windshield mirror with information about the vehicle, including the vehicle identification number (VIN). Once the vehicle is complete, it is parked in a lot until shipped to the dealer. Until recently, locating an individual car in the lot required a lengthy search. RTLS allows staff to quickly find individual cars by matching the VIN with the tag in a database, and using RTLS to triangulate the exact location of the tag. The tags are removed once the car is shipped to the dealer, and used again in another vehicle.

The same plant may use RTLS for other applications. RTLS tags fitted with alert buttons are used on component bins on the assembly line. They are manually activated whenever component inventory hits the reorder point, and then matched with information in a database prompting reorder and delivery of components to the exact location required. This system has lowered the risk of shortage and allowed inventory reduction, facilitating the execution of JIT management.

Active tag application: Smart and Secure Tradelanes (SST)

Container monitoring is considered a major security issue in many countries. The US Homeland Security Agency introduced the Smart and Secure Tradelanes initiative (SST) with the objective of identifying each container, including its contents, and securing cargo containers at their point of origin using special RFID tags that, once sealed, could not be opened in transit without damaging the tag. This reduces security risks by ensuring the integrity of ocean-going containers between their outbound ports and their destination ports in the US.

The SST initiative has led the International Organization for Standardization (ISO) to approve the standard ISO 18000-7, which selected the frequency for tags in ocean-going containers. The US Federal Communications Commission (FCC) and China's State Radio Regulatory Commission (SRRC) have supported this frequency band for active RFID tags in security seals for containers—a critical step for establishing seamless cross-border shipments and for encouraging other countries to adopt the same standard.

Several of the world's major ports have already built RFID networks for container tracking. (Ironically, US ports lag far behind in adopting this technology.) The port of Antwerp, the largest in the world, uses RFID to monitor all containers within its premises to ensure proper handling of containers with perishables and to maintain their security, while the port of Singapore now uses RFID seals on all containers bound for US seaports.

Military Applications

Passive tag application: Soldier dog tag

US soldiers have been wearing “dog tags” around their necks since World War I. Recently, the Office of Naval Research developed smart dog tags that carry more information than just name and rank. The dog tags are used by rescue personnel to identify a wounded soldier, access medical history, provide custom medical care and keep a record of treatment given for future use. These tags carry a variety of data (such as age, allergies, blood type, medical history and immediate treatment records) that improves the chances medics give the right treatment to an injured soldier. Signal ubiquity is another advantage of smart tags because they can be read through military clothing such as chemical and biological suits, body armor vests and field jackets (Gilbert, 2002, Williams, 2005).

Conventional triage uses a paper tag system, in which tags can be soiled or misplaced. Using smart tags, medics may be able to provide faster and more efficient treatment to injured soldiers. After treating an injured soldier on the battlefield, a medic can use a handheld reader to write information to that individual’s dog tag indicating the type of medical care the soldier received. Medics in the hospital would know the treatment provided in the field, expediting the prioritization of casualties. Estimates using trial data indicate that smart dog tags may reduce field losses by 30%. Because time is the enemy of critically injured personnel, this triage speed can increase a soldier’s chances of surviving injury.

Passive tag application: Standardized supply-chain tag

Alongside the initiatives led by Wal-Mart and other major retailers, as well as the initiatives in the pharmaceutical industry driven by the US Food and Drug Administration, the US Department of Defense (DoD) has supported the Electronic Product Code (EPC) architecture for a globally open RFID system using passive tags. The main application of this network configuration is supply-chain management, replacing the use of barcodes. The operational need here is to identify each item in a container and to create an updated shipment manifest to improve information flow in the supply chains.

The Navy's Fleet Industrial Supply Center (FISC) in Norfolk, Virginia, implemented a passive RFID inventory control in November 2003. The site receives less-than-container-load shipments from military depots, shippers and vendors from all over the US and consolidates these into oceangoing 20- and 40-foot containers for export. In the past, manual processes generated shipping errors, so the site implemented the RFID-based system to improve shipping accuracy. Goods are tagged and read as they pass into a container, while the system generates a shipping manifest. The manifest is electronically written to an active tag attached to the container's lock.

Justification for the new system comes from fewer errors, faster loading times and reduced labor requirements. The combination of passive tags (for individual item shipment) with active tags (to track whole containers) enhances total inventory visibility within the Department of Defense, which improves military capabilities (Estevez & Geary, 2004).

Semi-passive tag application: Night-vision goggles

The ability to deny enemy's access to critical technologies is a military priority. Night vision technology is regarded as a major tactical advantage in the military community, giving the troops the ability to control the night. In recent years, the design of night-vision goggles has incorporated RFID tags so as to identify and locate an individual goggle to allow recovery if lost, and to deactivate the goggle if it can't be recovered to prevent it being used by the enemy. The semi-passive tag used in night-vision goggles works through the same "backscatter" principle as in passive tags, as mentioned above. But, it contains a battery that powers the microchip, thus relaxing the need for high-powered readers. The battery provides greater signal strength, extending the tag's range, which makes the goggles easier to locate. The readers have also been improved, both in read range and in their ability to locate each goggle tri-dimensionally within a few inches.

The other important functionality provided by the tag is the ability to remotely deactivate it, if it cannot be retrieved. If the approximate location is known, but the goggle cannot be located or it is unsafe to retrieve it, it may be remotely deactivated by a helicopter flying above the area to prevent the enemy's access to its capabilities (Gilbert, 2002).

Semi-passive tag application: Food ration (MRE) tag

Before Sysco started trials of semi-passive temperature-sensing RFID tags, the US Army identified a need for such devices to monitor its combat feeding program. The army found that MREs (meals ready-to-eat) were significantly affected by the extreme temperature conditions encountered in Iraq during Operation Desert Storm. The three-year shelf life of rations stored at 80°F was cut to six months at 100°F and down to just one month at 102°F. This created an operational need to identify individual MRE pallets and to record temperature at regular intervals to assess the remaining shelf life of each MRE pallet.

Because of the temperature-induced deterioration of MREs, the Army combat feeding program decided on a large-scale test program using open standard EPC-compliant semi-passive tags with temperature sensors on each pallet of MREs at its San Joaquin, CA, distribution center. The idea of the program was to sense temperatures and to use a shelf-life model to predict the anticipated remaining life of rations to ensure that MREs sent to troops in operating areas are used before their shelf life expires.

A computer-generated shelf-life model based on the temperature data collected by the RFID tags was incorporated in the program. The model analyzes the data and produces an estimate of the remaining shelf life for the MREs, giving each pallet of MREs its status: a green light means they are ready to go; a red light means they have exceeded their shelf life; and a yellow light indicates the need for more detailed inspection to determine their condition (Gilbert, 2005; Hernandez & Thomas, 2005).

Active tag application: Job shop tag

Tobyhanna Army Depot, Pennsylvania, recently adopted a RTLS system using active tags to identify, locate and track components for a more efficient re-assembly system in its radar remanufacturing process. Upon receipt, each radar system is disassembled, and its components are distributed to several different job shops where they are serviced before reassembly and testing. The RTLS system prevents items from being lost in the shop, reducing total cycle time of the refurbishment process, reducing labor costs associated with manually tracking and finding parts, and lowering total inventory costs. The system automatically generates email alerts if items dwell too long in any workstation, and the long read-range of the active tags enables tagged items to be found in any location in the plant. This set of capabilities is quite useful in this shop where nearly all orders are made of unique jobs in a cluttered environment, making the queues in each station very hard to manage. Active tags are proactive in transmitting their data, so it keeps assets visible to personnel who manage the overall remanufacturing process even though these assets are distributed across different physical locations. This enables the reassembly process to be more efficiently managed.

An independent study of Tobyhanna estimated that the payback of the initial investment was less than one year, based on labor savings alone. The RTLS system also reduced cycle time by 10 to 35 days, which increases radar uptime and, therefore, improves defense capabilities.

Active tag application: Total Asset Visibility (TAV)

The DoD first became interested in RFID technology for supply-chain applications during the first Gulf War. At supply depots in Saudi Arabia and Bahrain, logistics staff had to manually inspect arriving containers for their contents. It is estimated that 25,000 out of 40,000 containers were never inspected, resulting in

$2.7 billion dollars of unused goods sitting at depots for months or years after the war ended. To prevent similar problems in the future, the DoD introduced its ITV (In-transit Visibility) program in 1993 to increase the visibility of shipments. In July 2002, the DoD issued a directive to tag all air pallets and containers with active RFID tags. The idea was to identify each container, including its contents, and to locate and track containers as they move from factory to frontline and back.

The DoD's ITV network has grown into the largest active RFID-enabled cargo tracking system in the world, with over 800 reading stations in 45 countries, providing information about equipment and cargo in 25,000 containers that pass through air, sea and rail terminals each day (Verma, 2005).

Using this system, the US Army estimated a 30% reduction in logistics assets required for the humanitarian operations in Somalia and Bosnia. The UK military, which also uses the system, estimated it achieved a 7% reduction in total logistics costs during Operation Iraqi Freedom. Other justifications for using the system include the ability to locate goods anywhere in the network (for instance, for expediting) and a reduction in the "bullwhip" effect occurring as a result of over-ordering. ITV has also been adopted as the standard for container tracking by NATO, Israel and Australia.

V. Selection of RFID Technology

In this section, we analyze the RFID cases described earlier. The approach we follow in this analysis rests on a simple premise that the choice of technology configuration is dictated by the operational needs in a business situation. Thus, in each case we first identify the operational needs and the choice of technology configuration. Next, we assess in a qualitative manner the correlation between these two to develop a better understanding of how RFID technology is chosen in practice. Finally, we propose conceptual frameworks in the form of a set of rules that managers can use to select the appropriate RFID technology configuration.

Table 3. Classification of Case Studies Based on the Choice of Technology Configuration

Range	**Passive**	**Semi-passive**	**Active**
LF	*Livestock tag (Open)*	*Smart tires (Closed)*	
HF	*Soldier Dog tag (Closed)*		
UHF	*Railcar tag (Open)* *Standardized supply-chain tag (Open)*		*Smart and Secure Tradelanes (Open)* *Total Asset Visibility (Open)*
Microwave	*Toll tag (Closed)*	*Night-vision goggles (Closed)* *Refrigerated trailer tag (Open)* *Food ration (MRE) tag (Open)*	*Vehicle tag (Closed)* *Job shop tag (Closed)*

As a starting point in analyzing these cases, we identified the technology configuration used in each case. Table 3 classifies each case study in two dimensions of RFID technology configuration: tag type (active, passive or semi-passive) and frequency range (LF, HF, UHF or microwave). It also indicates the choice of network architecture (open or closed) for each case. We notice that not all cells in the table are utilized. Because of the recent penetration of the Electronic Product Code (EPC) standard, certain frequencies have become more popular.

To develop a generally applicable set of operational needs, we analyzed all cases and identified specific operational needs satisfied by RFID technology in each case. Thereafter, through a process of trial and error, we finally arrived at a super-set consisting of seven generic operational needs:

Read distance—distance between reader and tag. For the purposes of this paper, we define short distance as less than 10 feet, medium as 10-30 feet, and long range as anything over 30 feet.

Read rate—number of tags that can be read per time unit, or, how fast a tag can be detected by a reader and information be exchanged. RFID varies in its read-speed; this primarily depends on the frequency in which the tag operates.

Real-time asset location—need to identify a tag's precise physical location. For the purposes of this paper, we define "precise" location as within less than five feet in a two-dimensional space.

Process security—need to prevent third party access to signal. RFID tags are typically "promiscuous": active tags periodically broadcast a signal, and passive tags will typically broadcast to any reader that interrogates them. Therefore, users need to select tags that fit their security needs. For example, to protect tag information, one may choose tag encryption or proprietary identification systems.

Single- or multi-party access to information—number of organizations needing access to tag information. Single-party systems can use any manufacturer's RFID technology because there is no requirement for interoperability with other parties. Multi-party systems need tags that all parties in the system can access with high levels of interoperability. These systems, therefore, require a commonly accepted set of standards for tags.

Information richness—amount of data transmitted by tag. Tags vary enormously in the amount and type of data that they can store. For the purposes of this paper, we define low levels of information richness as "license plate" tags that only exchange an identification number (some cases we observed had tags that stored 12, 23, 96, 110 or 128 bits of data). We define high information richness as tags with many kilobytes of memory (for example, ocean-going container tags with 128 Kbytes of memory). Medium levels of information richness involve smaller amounts of memory (for example, sensor tags with 4 Kbytes of memory).

Medium of concern (transmission hurdle)—physical hurdles that interfere with data transmission between the tag and reader. This includes interference by fluids (water, mud, snow or oils), solids (rubber, plastic, glass and even animal flesh), and packaging materials (metal cans or wood pallets). Finally, the walls and equipment in the surrounding environment may interfere with the transmission.

Having identified the operational needs and the choice of technology configuration for each RFID case, we captured this data in a comprehensive manner in Table 4.

Table 4. RFID Applications—Operational Requirements and Technology Choice

Applications		Minimum Requirements							Choice of RFID		
Case	Case Type	Read distance	Read rate	Real-time location	Process security	Single or multi access to information	Information richness	Medium of concern (transmission hurdle)	Network Type	Tag Type	Frequency
Toll tag	CIV	Med	Very High	No	Low	Single	Low	none	Closed	Passive	MW
Livestock tag	CIV	Short	Low	No	Low	Multi	Low	Plastic, flesh, mud and snow	Open	Passive	LF
Railcar tag	CIV	Med	High	No	Low	Multi	Low	none	Open	Passive	UHF
Soldier dog tag	MIL	Short	Low	No	High	Single	Med	Plastics, fabrics and fluids	Closed	Passive	HF
Standardized supply-chain tag	MIL	Med	High	No	Med	Multi	Low	none	Open	Passive	UHF
Smart tire	CIV	Short	Low	No	Low	Single	Med	Rubber	Closed	Semi-passive	LF
Refrigerated trailer tag	CIV	Med	High	No	Low	Multi	Med	none	Open	Semi-passive	MW
Night-vision goggles	MIL	Med	Very High	No	High	Single	Med	none	Closed	Semi-passive	MW
Food ration (MRE) tag	MIL	Med	High	No	Low	Multi	Med	none	Open	Semi-passive	MW
Vehicle tag	CIV	Long	Very High	Yes	Low	Single	Low	Glass	Closed	Active	MW
Smart and Secure Tradelanes (SST)	CIV	Long	High	No	High	Multi	High	none	Open	Active	UHF
Job shop tag	MIL	Long	Very High	Yes	Low	Single	Low	none	Closed	Active	MW
Total Asset Visibility (TAV)	MIL	Long	High	No	High	Multi	High	none	Open	Active	UHF

The purpose of developing Table 4, as mentioned earlier, was to develop a better understanding of how RFID technology is being chosen in practice. Hence, the minimum requirements lead to the choice of technology configuration discussed below.

For many applications, *read distance* is a critical variable in the choice of RFID. For instance, supply-chain applications often need to read all materials as they cross the dock gate, which means read distances must be sufficient to cover the area of the gate (usually around 12 feet). In other applications, read distance is less important than other factors. For instance, subdermal implants are frequently used in animal tagging, but these only need to be read at a few inches by an operator using a handheld reader. Read-distance requirements can dictate the use of active tags, which far outperform passive tags on this metric.

One case we studied demonstrates the need for high *read rate* better than any other: toll road tags in Singapore. The need here was for a system that could read a tag on high-speed vehicles as they pass toll stations. Because of the small amount of time that the tag is in the vicinity of the reader, this requires a very fast read-speed in order to be assured that the tag is successfully read. This dictated the use of microwave RFID because of its superior read-speed performance (all other things being equal). By comparison, tags read one-at-a-time using a handheld reader (for instance, soldier dog tags) have a relatively low requirement for read speed. In applications where the user needs sensor data (such as temperature information), read speed again becomes an important metric governing tag selection.

We studied several applications that demonstrate the need for *real-time asset location*. In automakers' vehicle parks, the chief requirement is the ability to accurately locate individual vehicles in order to reduce the time workers spend searching the parking lot. Similar advantages accrued in the remanufacturing job-shop application we studied, where the ability of managers to monitor the exact location of parts in a job shop (and, hence, expedite them) was critical to improving the efficiency of the final reassembly process. However, in many other applications, location precision is not required. In some applications, reader location acts as a surrogate for tag location, e.g., the standardized supply-chain tag is usually sufficient to know that a tag is in the vicinity of a reader in a given facility. In yet other applications, if the tagging is manual, location is implicit information, e.g., livestock tags.

Of the cases we studied, military applications best illustrate the need for *process security* (i.e., securing tags to outside investigation). This need led technology developers to create encryption techniques for passive tags, which require a reader to write a secret code to a tag before the tag will respond. Security is also an important variable in the SST (Safe and Secure Tradelanes) initiative, where active tags with a variety of sensors are used to ensure that unauthorized personnel do not tamper with oceangoing containers. Even in domestic supply-chain applications, managers may have reasons for securing standard supply-chain tags with encryption mechanisms in order to stop unauthorized parties from gaining access to detailed information about the movement of goods; this can be important for securing high-value items such as vaccines or electronic goods.

Of the cases we studied, railcar tagging represents a significant example of a *multi-party* RFID system (it is our understanding that this was the first major example of a multi-party system that was actually implemented). Because railcars travel on tracks owned by many parties, an infrastructure of multi-party RFID readers was required. Furthermore, these multiple parties also needed to share information about the location of individual railcars among them. In this case, the fact that the railroad industry had a pre-existing and strong industry association was critical in sponsoring the implementation of this multi-party initiative to adopt a standard RFID technology. Many other applications are *single party*. For example, toll tags are typically single-party systems, as are many manufacturing applications of RFID.

Information richness is often a critical variable in tag choice. For instance, in the TAV initiative, oceangoing containers are used as mobile warehouses for inventory. Therefore, the tag on the container needs a high memory capacity so operators can read a container in a yard and know the inventory inside without having to open the container and manually account for its contents. Similarly, sensor tags involve rich information exchange. This requirement dictates the use of semi-passive tags with enough memory to accumulate temperature readings for a period of time, for instance, in applications in refrigerated trailers. In other applications, information exchange is limited to a unique identification number, such as toll tags, livestock tags or standardized supply-chain tags.

Medium of concern (i.e., transmission hurdle) often dictates what type of RFID is able to exchange data with its reader given the operating surroundings. For instance, as a minimum requirement, medical personnel need a soldier dog tag that can be read even when it is covered with fluids such as blood. It is also an advantage that the tag can be read easily through a secure plastic casing and through clothing materials. Tires and livestock applications are other examples where the media may affect tag performance. LF and HF tags often perform better in these restrictive environments. In still other applications, the medium is irrelevant. For instance, toll tags are often placed on vehicle license plates, and railcar tags are placed on the side of the car—locations that ensure there is nothing except air between the tag and reader. In these applications, passive UHF and microwave tags can be selected. All other things being equal, active tags often make a better choice where various mediums interfere with the transmission of RFID signals since they can beacon a stronger signal that often travels farther within various media.

It is important to realize that some of these requirements must be strictly met with a specific type of tag. For example, if the operating medium is opaque to UHF and microwave, then LF or HF must be used; otherwise, the reader cannot communicate with the tag. Other requirements may be satisfied with tags that exceed the operational needs, or using a technical solution that enhances the performance of the selected technology. The manager should make the selection recognizing the limits imposed by technical feasibility and operational needs.

THIS PAGE INTENTIONALLY LEFT BLANK

VI. Justification of RFID Technology

Automation technologies require major investments of capital, attention and enthusiasm. Hence, the manager needs to acquire significant buy-in in order to obtain the support necessary to undertake these investments. This buy-in requires, among other things, a solid justification that can be measured in terms of financial or operational benefits and the investment and operating costs associated with the technology.

Financial and Operational Benefits of RFID

In general, RFID technologies are adopted because they are an economical approach to satisfy an operational need and gain competitive advantage. In a civilian environment, the payoff is usually characterized in terms of increased revenue or better productivity. In the military environment, this payoff is either characterized as increased "readiness," or the cost to increase "readiness" (a military expression that encompasses the availability and reliability of weapon systems critical for a warfighter). In Table 5 we consider the benefits resulting from adopting RFID technology in each particular application. We note that RFID technology has contributed with improvements in several competitive operations capabilities: quality (assurance or customer service), speed (process capacity or cycle-time), flexibility (service customization) and cost (labor reduction or theft control). In some cases RFID technology has even enhanced some tactical capabilities such as asset location and process security—important concerns for both military and civilian operations.

Table 5. RFID Applications—Resultant Benefits

Case	Case Type	Benefits Resulting from the Use of RFID	Quality Assurance	Customer Service	Process Security	Process Capacity	Cycle-time	Item Location	Cost
Toll tag	CIV	Greater capacity, labor reduction, identification for peak load pricing and demand management		*		**	**		*
Livestock tag	CIV	Health control and product quality, inventory management	*		**			*	
Railcar tag	CIV	Reduced human error, accurate item location and order confirmation		*				**	*
Soldier dog tag	MIL	Custom medical care, reduced cycle time and error rate, lower mortality	**				*		
Standardized supply-chain tag	MIL	Accurate shipment, increased speed and capacity, lower labor costs, location information				*	**	*	**
Smart tire	CIV	Better quality of information, lower operating cost	*		*				**
Refrigerated trailer tag	CIV	Better quality of information, ownership control, increased security	**		*				
Night-vision goggles	MIL	Access control, location information			**			*	
Food ration (MRE) tag	MIL	Improved quality based on improved monitoring and control	**			*			
Vehicle tag	CIV	Lower cycle time, higher productivity, location information					*	*	**
Smart and Secure Tradelanes (SST)	CIV	Increased security, increased capacity, lower cycle time			**	*	**		*
Job shop tag	MIL	Higher capacity, reduced cycle time and labor costs, location information				**	*	*	*
Total Asset Visibility (TAV)	MIL	Accurate shipment, lower inventory obsolescence		*			*	*	**

Legend: CIV = civilian, MIL = military, ** = primary benefit, * = additional benefit

Within the RFID industry, there is considerable concern about identifying the benefits of RFID technology deployment (Wyld, 2005, p. 29). This is especially true as many suppliers struggle with mandates from major buyers (Wal-Mart, Target and others), mainly because it is very difficult for some to understand the benefits. Table 5 highlights the primary benefit realized in each application discussed in the previous section, as well as the additional benefits provided by the technology. Notice that the benefits provided by a given system design depends on the process where it is deployed. If the objective is to simply manage product flow, passive tags using the standard EPC frequency are the logical choice. However, minimalist designs may generate little results (in fact, if product flow is the only objective, why not use the barcode?). So, the manager must keep in mind that, in order to justify the adoption of RFID technology, there must exist other benefits associated with the investment—preferably benefits that enhance the competitive capabilities of the organization.

RFID is not the first automation technology that has caused frustration among early adopters. In the 1980s, manufacturers encountered the same difficulty in estimating costs and benefits of computer-integrated manufacturing (Kaplan, 1986). However, open-network RFID adds another level of difficulty inasmuch as it requires that many players—not just one company—understand and benefit from the value provided by the technology, even if that value is not easily measured. Every firm in the network must understand the utility created by the technology and be able to capture some of this utility in the form of revenue increase and/or cost savings. Otherwise, the network suffers from unsustainable externality that leads to some players not making the appropriate investment. For instance, in retail applications, there are two major benefits from using RFID: better inventory management with the reduction of the bullwhip effect (Fleisch & Tellkamp, 2005) and better on-shelf availability (Langford, 2005). However, both benefits lean strongly in favor of the retailer, while the manufacturer bears most of the variable cost. Supply-chain partners with significant information sharing experience, such as Wal-Mart and Procter & Gamble, benefit from improving the quality of real-time information that they can share since the benefit of using the information outweighs the costs of implementing and maintaining the technology. But the same benefits have not been clearly observed by many small retailers and manufacturing companies or other organizations that do not share supply-chain information with buyers or suppliers.

Some prominent RFID applications are geared towards increasing a facility's capacity. However, the value of increased throughput is non-trivial to calculate. For example, how should we measure the value of increasing throughput at a port of entry operating at full capacity (such as the Port of Los Angeles and Long Beach) with a land constraint that prohibits expansion? Similarly, how should we measure the value of increased capacity at a tollbooth with similar land constraints—as in the many urban tunnels and bridges in New York City, Boston or San Francisco? In these cases, increased throughput is needed, but the actual value of this increased throughput cannot be easily measured since measurement requires comparison to the situation where the technology is not implemented; *that* is very hard to do.

Likewise, the benefit for the Department of Defense, an early adopter of RFID technology, is hard to quantify. Although the cost savings associated with better inventory management can be calculated with the appropriate financial metric, the value of "readiness" (an important performance measure in the military community) is much harder to trace back to any particular technology investment (Estevez, 2004). This challenge is similar to measuring the benefit gained with other subjective improvements, such as better quality management or better customer service, where the correlation between these management practices and financial performance measures is unclear (Kaplan, 1986). Quantification is even more difficult within the framework of traditional cost-benefit analyses of the rudimentary kind conducted in most organizations (Doerr & Gates, 2004).

The Costs of RFID operation

An RFID network incurs costs that are related to its implementation and costs that are related to its operation. The implementation costs and the costs related to learning how to use the technology are quite significant because it is a technology that usually requires significant time to master. Moreover, there is no evidence that the learning cost varies with the size of the system. Since high fixed costs indicate economies of scale, there is little incentive for small companies to adopt RFID outside the structure of a large network. The initial learning cost creates incentives for large organizations to become early adopters because they can amortize fixed costs more easily than small organizations can, which perhaps explains the early leadership of Wal-Mart and the DoD.

The initial implementation requires the purchase and installation of hardware and software, as well as the managerial drive, to execute the project. The system operation requires manning and maintaining the system. Moreover, an open system requires continual replenishment of the tag population in the upstream stages of the supply chain.

During the growth phase of the operation, when the system is expanding and more objects are being tracked, the operation requires the continuous addition of new tags and the occasional addition of readers to prevent the creation of bottlenecks. Open system applications encourage, and often require, the continuous introduction of new disposable tags. However, if the tags are reusable, the operation should include the collection of used tags (but the replenishment with new tags is not completely avoided since some of them are inevitably lost or damaged in the process).

Open systems tend to create an asymmetry between the beneficiaries of RFID investment and those who bear the variable costs of maintaining the system. Although all parties must invest in the infrastructure (readers, hardware and software), only the manufacturers bear the cost of tagging their products, while distributors and retailers (concerned with managing a very large number of stock-keeping units) have the benefit of inventory control with relatively little direct cost. This problem was also observed earlier with the introduction of electronic data interchange (EDI) and was discussed by Riggins et al. (1994). It is also the likely reason behind the small companies' reluctance to adhere to the retailers' request to tag all products.

The cost and benefit of closed RFID networks are usually born and enjoyed by a single organization. The initial implementation process is not too different from the implementation of an open network. However, it is easier to design a system relying on reusable tags, since the network belongs to a single entity: a company or a consortium of companies with clear policies regarding the operation of their RFID network. Because of the clear boundary around the system and the relative stability of the network structure, closed networks usually have a fixed number of reusable tags that can be amortized over a long period of time. New tags are introduced in the system only during the growth phase and to replace damaged tags. Consequently, investment on closed RFID networks using active tags may show a payback period as short as 12-18 months (Armanino, 2005).

Real Options Approach to RFID Investments

Net Present Value (NPV), Return on Investment (ROI), and Payback Period are tools commonly used to evaluate routine investments in technology when the costs and benefits of technology implementation are clear-cut and can be easily quantified. For example, investment in a machine that replaces a certain amount of labor effort can be evaluated by estimating the NPV of the initial investment outlay and the reduced labor costs over the economic life of the machine. However, these tools are mostly inadequate when it comes to evaluating investment in an infrastructure technology that is strategic and long-term in nature. The main reason for such inadequacy is that such technology is usually characterized by the myriad ways it can be deployed, with a high level of uncertainty associated with its benefits. Projected cash flows based on the initial use of the technology seem small in comparison to the investment required. Or, the discount rate chosen to compensate for the risk becomes so high that it makes the NPV look tiny or negative. Considering the level of uncertainty coupled with the embedded options available in RFID's adoption, we believe that Real Options Analysis is a more suitable approach for valuing such technologies.

An option represents freedom of choice after the revelation of information, and it is a right but not an obligation. Options on financial instruments have been used in financial markets for a number of years, but the idea of real options (i.e., options pertaining to the future use of real things) has emerged only in last decade (Amran & Kulatilaka, 1998; Copeland & Antikorov, 2003; Adner & Levinthal, 2004; Munn, 2002). The main idea underlying this approach is that when evaluating the projected return on RFID investments, the manager also considers the value of future RFID-related opportunities (options) that these current investments might generate. In using the real-options analysis, one can view RFID technology as a bundle of capabilities that may have immediate paybacks but may also be “stepping stones” to future capabilities. It may, therefore, make sense for the manager to consider the possible future value of some of these stepping-stone investments that pre-position the organization for future opportunities that can be grasped when key uncertainties are adequately resolved (i.e., technology capabilities, customer acceptance, etc). At that moment, the option to use (or not use) RFID technology may be exercised or allowed to lapse. The real-options methodology provides tools and techniques for capturing this value-creating aspect of RFID investments. RFID Technology offers a number of valuable, real options (Patil, 2004):

- **Growth**: A small initial investment in RFID as a data-collection platform can serve as an infrastructure for other valuable projects in the future. For example, use of RFID for pallet-level tracking may be extended to item-level tracking in the future.
- **Flexibility**: A resource may be acquired initially with a specific purpose in mind, but (depending on the flexibility of the resource) it may be used in the future to also serve some other need. For example, a hand-held reader used at the check-out counter may be used within cycle counting to better manage purchasing and inventory-control functions.
- **Innovation and learning**: New technologies are invariably associated with steep learning curves, and hence, hands-on learning is one of the best ways to better understand the new technology and its potential applications. For example, the use of RFID allows an organization to collect information about products moving through the supply chain. This ability can be subsequently leveraged to create product tracking information to improve customer service and delivery reliability.
- **Waiting**: At times, the value of waiting to adopt a technology until better market information becomes available may exceed the value of its immediate adoption.

For example, in applications where the existence of standards is important, there is value in waiting to see which technology becomes the industry standard.

- **Abandonment**: The ability to abandon and walk away from a technology if it becomes a failure is a valuable option to retain in early technology adoption decisions.

It should be noted that RFID not only generates value directly in the short-term but also enables introduction and implementation of various value-generating applications in the long run. Hence, we recommend that in evaluating and justifying an investment in RFID, a manager follow an approach that is a hybrid of the traditional tools of NPV or ROI and the real-options theory. For example, investment in RFID can be viewed first as an acquisition of a data-collection platform that reduces the costs of data collection by making the current data-collection process more efficient. The NPV of this base level of benefits is first assessed. Next, the manager should identify the options applicable in the given situation and estimate their associated NPVs based on when these options could be exercised and the value of the applications they represent. The combined NPV of the base level of benefits and the options discussed above should provide sufficient basis for a manager to meaningfully evaluate and justify the investment in RFID.

VII. Conclusions

RFID is a promising technology, and many organizations are presently contemplating its adoption to improve the operational performance of a variety of processes. As in the case of any new technology adoption, managers must consider two major issues before adopting the RFID technology: selection of the right configuration and justification of the technology investment. Helping managers deal with these issues is the main objective of the current research.

Since the use of RFID technology in business application is quite recent, we used the methodology of case research. Specifically, we studied 13 cases of RFID applications, in both civilian and military settings, so as to develop a better understanding of how RFID technology configurations are selected in practice. In each case, we identified the operational needs and the choice of technology configuration made by the firm or organization. This data was further analyzed in a qualitative manner to determine if there exists any relationship between these two and how operational needs influenced the choice of technology configuration. The results of this analysis were used to propose conceptual frameworks in the form of sets of rules that a manager can use to select the appropriate RFID technology configuration.

Since justification is an important issue in adopting any new technology, a manager must identify an approach that is most suitable for the justification of his/her particular choice of RFID technology. To provide a managerial guideline in dealing with this issue, we evaluated appropriateness of traditional methods such as net-present value analysis and return on investment, as well as the more recent real-options analysis. We found that, given the level of uncertainty associated the resulting benefits of RFID and the existence of multiple options available in its deployment, the real-options approach (as opposed to traditional methods) is more appropriate for valuing RFID technology.

RFID technology is in its early phases of adoption, and we are just scratching the surface of the benefits that this technology can provide. The principle advantage of RFID technology is that it can not only inform a reader and system what and where an item is but also what condition the item is in. As a sophisticated data-gathering platform, RFID technology can be used to support and enhance the decision and control capabilities in computer-integrated manufacturing and service operations; in many ways, therein lays the greatest potential for RFID.

VIII. References

Adner, R., & Levinthal, D. A. (2004). What is not a real option: Considering boundaries for the application of real options to business strategy. *Academy of Management Review*, 29(1), 74–85.

Amran, M., & Kulatilaka, N. (1998). *Real Options: Managing Strategic Investment in an Uncertain World*. Oxford, UK: Oxford University Press.

Argote, L., & Ingram, P. (2000). Knowledge transfer: A basis for competitive advantage in firms. *Organizational Behavior and Human Decision Processes*, 82(1), 150–169.

Armanino, M. (2005). Personal interview with M. Armanino, V-P sales and field operations, WhereNet, Inc. by N.Dew and G. Ferrer, July 27, 2005.

Artle, R., & Averous, C. (1973). The telephone system as a public good: Static and dynamic aspects. *The Bell Journal of Economics and Management Science*, 4(1), 89-100.

Barney, J. (1991). Firm resources and sustained competitive advantage. *Journal of Management*, 17(1), 99-114.

Cattle-tagging technology. (2005). *RFID Journal*. Retrieved October 29, 2005, from http://www.rfidjournal.com/article/articleview/1033

Cohen, M.A., & Apte, U.M. (1997). *Manufacturing automation*. New York: Irwin (McGraw-Hill).

Cohen, W. M., & Levinthal, D.A. (1990). Absorptive capacity: A new perspective on learning and innovation. *Administrative Science Quarterly*, 35(1), 128-152

Copeland, T., & Antikorov, V. (2003). *Real options: A practitioner's guide*. New York: Texere, Thomson Publishing.

David, P.A. (1985). Clio and the economics of QWERTY. *American Economic Review,* 75(2), 332-337.

Dew, N. (2006). *The evolution of the RFID technology system.* (Working paper). Monterey, CA: Naval Postgraduate School.

Eisenhardt, K.M. (1989). Building theory from case study research*. Academy of Management Review*. 14(4), 532-550.

Estevez, A. F., & Geary, S. (2004). Lessons from the desert. *Supply Chain Management Review*, (2004, November-December), 38-43.

Ferdows, K., & De Meyer, A. (1990). Lasting improvements in manufacturing performance: In search of a new theory. *Journal of Operations Management,* 9(2), 168-184.

Fleisch, E., & Tellkamp, C. (2005). Inventory inaccuracy and supply chain performance: A simulation study of a retail supply chain. *International Journal of Production Economics*, (In Press).

Gandal, N., Greestein, S., & Salant, D. (1999). Adoptions and orphans in the early microcomputer market. *The Journal of Industrial Economics*, XLVII (1), 87-106.

GAO. (2005, September). *Better strategic planning can help ensure DoD's successful implementation of passive radio frequency identification*. Defense logistics report GAO-05-345. Washington, DC: US Government Accountability Office. Retrieved September 12, 2005. http://www.gao.gov/new.items/d05345.pdf

Gilbert, R. (2002). Personal interview with R. Gilbert, Alien Technology Inc., by N. Dew, January 31, 2002.

Gilbert, R. (2005). Personal interview with R. Gilbert, Alien Technology, Inc. by N. Dewl March 27, 2005.

Guilford, S., & Kutis, M.C. (2005). *RFID benefits: Looking beyond ROI.* (MBA Professional Report). Monterey, CA: Naval Postgraduate School.

Hernandez, E.V., & Thomas, C.A. (2005). *Investigating the Department of Defense's implementation of passive radio frequency identification (RFID).* (MBA Professional Report). Monterey, CA: Naval Postgraduate School.

Kaplan, R.S. (1986, March-April). Must CIM be justified by faith alone? *Harvard Business Review* 47 (March-April 1986), 87-94.

Katz, M. L., & Shapiro, C. (1985). Network externalities, competition, and compatibility. *The American Economic Review*, 75(3), 424-440.

Lahiri, S. (2005). *RFID sourcebook*. Upper Saddle River, NJ: IBM Press.

Landt, J. (2001). *The shrouds of time: History of RFID*. Pittsburgh, PA: AIM, Inc.

Landt, J. (2002, September 9). Personal interview with J. Landt by N. Dew, FN LN].

Levitt, B., & March, J.G. (1988). Organizational learning. *Annual Review of Sociology,* 14, 319-340.

Majumdar, S. K., & Venkataraman, S. (1998). Network effects and the adoption of new technology: Evidence from the US telecommunications. *Strategic Management Journal*, 15 (11), 1045-1062.

Meredith, J. (1998). Building operations management theory through case and field research*. Journal of Operations Management,* 16(4), 441-454.

Munn, J. (2002). *Real options analysis: Tools and techniques for valuing strategic investments and decisions*. Hoboken, NJ: John Wiley and Sons.

NAVSUP. (2005, April). *Navy passive RFID BCA final report*. Washington, DC: US Department of Defense.

Nelson, R.R., & Winter, S.G. (1982). *An evolutionary theory of economic change*. New York: Belknap Press.

Patil, M. (2004, December). *Investments in RFID: A real options approach—A white paper from Patni Computer Systems, Ltd.* Retrieved December 18, 2005, from http://www.patni.com/downloads/tp_invst_RFiD_Real_optionApproach.pdf

Riggins F.J., Kriebel, C.H., & Mukhopadhyay, T. (1994). The growth of interorganizational systems in the presence of network externalities. *Management Science*, 40(8), 984-998.

Rohlfs, J. (1974). A theory of interdependent demand for communications services." *The Bell Journal of Economics and Management Science*, 5(1), 16-37.

Schilling, M. (2002). Technology success and failure in winner-take-all markets: The impact of learning orientation, timing, and network externalities. *Academy of Management Journal*, 45(2), 387–398.

Skinner, W. (1969). Manufacturing: The missing link in corporate strategy. *Harvard Business Review,* May-June 1969, 135-145.

Son, J-Y., Narasimhan, S., & Riggins, F.J. (1999, December 12-15). Factors affecting the extent of electronic cooperation between firms: economic and sociological perspectives. *Proceeding of the 20th International Conference on Information Systems*. Charlotte, NC, 556-560.

Srinivasan, R., Lilien, G. & Rangaswamy, A. (2004). First in, first out? The effect of network externalities on pioneer survival. *Journal of Marketing*, 68(1), 41-58.

Suarez, F.F. (2005). Network effects revisited: the role of strong ties in technology selection. *Academy of Management Journal,* 48(4), 710–720.

Szulanski, G. (1996). Exploring internal stickiness: Impediments to the transfer of best practice within the firm. *Strategic Management Journal,* 17 (Winter Special Issue), 27-44.

Szulanski, G., & Winter, S.G. (2000). Replication as strategy. *Organization Science,* 12(6), 730-743.

Teece, D., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management, *Strategic Management Journal*, 18(7), 509-533.

Verma, V. (2005). Personal interview with V. Verma, President & CEO Savi Technology, Inc. by N. Dew and G. Ferrer, August 29, 2005.

Von Hippel, E. (1994). “Sticky information” and the locus of problem-solving: Implications for innovation. *Management Science,* 40(4),429-439.

Voss, C.A., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management,* 22(2), 195-219.

Williams, D. (2005, August 4). Presentation. Naval Health Research Center.

Wyld, D.C. (2005). *RFID: The right frequency for government*. E-Government series. Washington, DC: IBM Center for The Business of Government.

Yin, R. (1994). *Case study research*. Beverly Hills, CA: Sage Publications.

Initial Distribution List

1. Defense Technical Information Center 2
   8725 John J. Kingman Rd., STE 0944; Ft. Belvoir, VA 22060-6218

2. Dudley Knox Library, Code 013 2
   Naval Postgraduate School, Monterey, CA 93943-5100

3. Research Office, Code 09 1
   Naval Postgraduate School, Monterey, CA 93943-5138

4. Robert N. Beck 1
   Dean, GSBPP
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

5. Keith F. Snider 1
   Associate Professor, GB/Sk
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

6. James B. Greene 1
   Acquisition Chair, GB/Jg
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

7. Bill Gates 1
   Associate Dean for Research, GB/Gt
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

8. Uday Apte 1
   Professor
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

9. Nick Dew 1
   Assistant Professor
   555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

10. Geraldo Ferrer 1
    Associate Professor
    555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

11. Karey L. Shaffer 1
    Program Manager, Acquisition Research Program, GB/Ks
    555 Dyer Road, Naval Postgraduate School, Monterey, CA 93943-5000

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.nps.navy.mil/gsbpp/acqn/publications

THIS PAGE INTENTIONALLY LEFT BLANK

2003 - 2006 Sponsored Acquisition Research Products

Acquisition Case Series

NPS-AM-06-008 Apte, Aruna U. The AEGIS Microwave Power Tube Case Study. December 2005.

UMD-CM-05-019 Lucyshyn, William, Rene Rendon, and Stephanie Novello. Improving Readiness with a Public-Private Partnership: NAVAIR's Auxiliary Power Unit Total Logistics Support Program. July 2005.

UMD-CM-05-018 Lucyshyn, William, and Stephanie Novello. The Naval Ordnance Station Louisville: A Case Study of Privatization-in-Place. August 2005.

NPS-CM-04-008 Lucyshyn, William, Jeffrey Cuskey, and Jonathan Roberts. Privatization of the Naval Air Warfare Center, Aircraft Division, Indianapolis. July 2004.

NPS-PM-04-010 Lucyshyn, William, Keith F. Snider, and Robert Maly. The Army Seeks a World Class Logistics Modernization Program. June 2004.

NPS-CM-03-005 David V. Lamm. Contract Closeout (A). September 2003.

Sponsored Report Series

NPS-LM-06-009 Apte, Uday M., Nicholas Dew and Geraldo Ferrer. What Is the Right RFID for Your Process? January 2006.

NPS-LM-06-005 Hernandez, Captain Emeterio V., US Air Force and Lieutenant Christopher A. Thomas, US Navy. Investigating the Department of Defense's Implementation of Passive Radio Frequency Identification (RFID). December 2005.

NPS-FM-06-004 Rios, Jr., LCDR Cesar G., US Navy. Return on Investment Analysis of Information Warfare Systems. September 2005.

NPS-AM-06-003 Komoroski, Christine L. Reducing Cycle Time and Increasing Value through the Application of Knowledge Value Added Methodology to the U.S. Navy Shipyard Planning Process. December 2005.

UMD-AM-05-021 Gansler, Jacques S., and William Lucyshyn. A Strategy for Defense Acquisition Research. August 2005.

UMD-CM-05-020 Dunn, Richard. Contractors in the 21st Century "Combat Zone." April 2005.

NPS-PM-05-017 Brianas, Christopher G. Department of the Navy Procurement Metrics Evaluation. June 2005.

NPS-CM-05-015 Johnson, Ellsworth K. III, Bryan H. Paton, Edward W. Threat, and Lisa A. Haptonstall. Joint Contingency Contracting. June 2005.

NPS-CM-05-013 Schwartz, Brett M., Jadon Lincoln, Jose L. Sanchez, and Leslie S. Beltz. Update of the Navy Contract Writing Guide Phase III. June 2005.

NPS-PM-05-012 Jenkins, Glenn E., and William J. Snodgrass, Jr. The Raven Small Unmanned Aerial Vehicle (SUAV): Investigating Potential Dichotomies between Doctrine and Practice. June 2005.

NPS-FM-05-009 Jones, Lawrence R., Jerry McCaffery, and Kory L. Fierstine. Budgeting for National Defense Acquisition: Assessing System Linkage and the Impact of Transformation. June 2005.

NPS-LM-05-008 Kang, Keebom, Kenneth Doerr, Michael Boudreau, and Uday Apte. A Decision Support Model for Valuing Proposed Improvements in Component Reliability. June 2005.

NPS-PM-05-007 Dillard, John T., and Mark E. Nissen. Determining the Best Loci of Knowledge, Responsibilities and Decision Rights in Major Acquisition Organizations. June 2005.

NPS-AM-05-006 San Miguel, Joseph G., John K. Shank, and Donald E. Summers. Navy Acquisition via Leasing: Policy, Politics, and Polemics with the Maritime Prepositioned Ships. April 2005.

NPS-CM-05-003 Rendon, Rene G. Commodity Sourcing Strategies: Supply Management in Action. January 2005.

NPS-CM-04-019 Lord, Roger. Contractor Past Performance Information (PPI) In Source Selection: A comparison Study of Public and Private Sector. December 2004.

NPS-PM-04-017 Matthews, David. The New Joint Capabilities Integration Development System (JCIDS) and Its Potential Impacts upon Defense Program Managers. December 2004.

NPS-LM-04-014 Apte, Aruna. Optimizing Phalanx Weapon System Lifecycle Support. October 2004.

NPS-AM-04-013 Franck, Raymond (Chip). Business Case Analysis and Contractor vs. Organic Support: A First-Principles View. September 2004.

NPS-LM-04-006 Ken Doerr, Ken, Donald R. Eaton, and Ira Lewis. Measurement Issues in Performance Based Logistics. June 2004.

NPS-CM-04-004 MBA Team. Update of the Navy Contract Writing, Phase II. June 2004.

NPS-CM-04-002 MBA Team. Marine Corps Contingency Contracting MCI. Revised Manual. December 2003.

NPS-CM-04-001 MBA Team. Update of the Navy Contract Writing, Phase I. December 2003.

NPS-CM-03-006 Tudor, Ron B. Auto-Redact Toolset for Department of Defense Contracts. September 2003.

NPS-AM-03-004 Boudreau, Michael W., and Brad R. Naegle. Reduction of Total Ownership Cost. September 2003.

NPS-AM-03-003 Dillard, John T. Centralized Control of Defense Acquisition Programs: A Comparative Review of the Framework from 1987-2003. September 2003.

NPS-CM-03-001 MBA Team. Transformation in DoD Contract Closeout. June 2003.

Working Paper Series

NPS-PM-06-002 Dillard, John T. When Should You Terminate Your Own Program? November 2005.

NPS-AM-06-001 Naegle, Brad. Developing Software Requirements Supporting Open Architecture Performance Goals in Critical DoD System-of-Systems. November 2005.

NPS-AM-05-010 Zolin, Roxanne V., and John T. Dillard. From Market to Clan: How Organizational Control Affects Trust in Defense Acquisition. June 2005.

NPS-AM-05-005 Boudreau, Michael. Cost as an Independent Variable (CAIV): Front-End Approaches to Achieve Reduction in Total Ownership Cost. June 2005.

NPS-AM-05-002 Yoder, Elliott Cory. The Yoder Three-Tier Model for Optimizing Contingency Contracting Planning and Execution. December 2004.

NPS-AM-05-001 Yoder, Elliott Cory. Engagement versus Disengagement: How Structural & Commercially-Based Regulatory Changes have Increased Government Risks in Federal Acquisitions. November 2004.

NPS-CM-04-016 Stevens, Brett. An Analysis of Industry's Perspective on the Recent Changes to Circular A-76. October 2004.

NPS-CM-04-012 Rairigh, Beth. Air Force Commodity Councils: Leveraging the Power of Procurement. September 2004.

NPS-CM-04-011 Engelbeck, R. Marshall. Using Metrics to Manage Contractor Performance. September 2004.

NPS-LM-04-009 Eaton, Donald R. Improving the Management of Reliability. August 2004.

NPS-AM-04-007 Naegle, Brad R. The Impact of Software Support on System Total Ownership Cost. July 2004.

NPS-LM-04-003 Eaton, Donald R. Enablers to Ensure a Successful Force Centric Logistics Enterprise. April 2004.

NPS-CM-03-002 Parker, Christopher and Michael Busansky. Transformation in DoD Contract Closeout. June 2003.

Acquisition Symposium Proceedings

NPS-AM-05-004 Acquisition Research: The Foundation for Innovation. May 2005.

NPS-AM-04-005 Charting a Course for Change: Acquisition Theory and Practice for a Transforming Defense. May 2004.

Technical Reports

NPS-GSBPP-03-003 Dillard, John T. Centralized Control of Defense Acquisition Programs: A Comparative Review of the Framework from 1987-2003. September 2003.

NPS-GSBPP-03-004 Boudreau, Michael W., and Brad R. Naegle. Reduction of Total Ownership Cost. September 2003.

Presentations, Publications and External Forums

Rendon, Rene. “Commodity Sourcing Strategies: Supply Management in Action.” Published as “Commodity Sourcing Strategies: Processes, Best Practices, and Defense Initiatives.” *Journal of Contract Management* 3, no.1 (2005): 7-21.

Doerr, Ken, Ira Lewis, and Donald Eaton. “Measurement issues in Performance Based Logistics.” *Journal of Public Procurement* 5, no. 2 (2005): 164-186.

Eaton, Donald, Ken Doerr, and Ira Lewis. “Performance Based Logistics: A Warfighting Focus.” *US Naval Institute Proceedings.* (In Press).

Doerr, Ken, Donald Eaton, and Ira Lewis. “Performance Based Logistics.” Presented to the International Defense Acquisition Resource Management Conference. Capellen, Luxembourg, 2004.

Kang, Keebom, and Ken Doerr. Workshop: Metrics and Performance Evaluation in Performance Based Logistics. Presented at Future Naval Plans & Requirements Conference. San Diego, CA. October 2005.

Boudreau, Michael, and Brad Naegle. “Total Ownership Cost Considerations in Key Performance Parameters and Beyond.” *Defense Acquisition Research Journal* 38, no.2 (2005): 108-121.

Boudreau, Michael, and Brad Naegle. Workshop: Setting up Acquisition for Total Lifecycle Supportability Performance. Presented at the Institute for Defense and Government Advancement Conference: Total Lifecycle Systems Management. Arlington, VA. 2005.

Kang, Keebom, Ken Doerr, Uday Apte, and Michael Boudreau. “Decision Support Models for Valuing Improvements in Component Reliability and Maintenance.” Submitted to the Journal of Defense Modeling and Simulation in July 2005 for possible publication. Currently the article is being reviewed by referees.

Franck, Raymond (Chip). "Business Case Analysis and Contractor vs. Organic Support: A First–Principles View." Presented at the Western Economic Association International Annual Conference. San Francisco, CA. 5 July 2005.

Dillard, John, and Mark Nissen. "Computational Modeling of Project Organizations under Stress." In review.

Dillard, John. "Centralization of Defense Acquisition Programs." Accepted for publication in the Defense Acquisition Research Journal (2005).

Nissen, Mark E., and John Dillard. "Computational Design of Public Organizations." In review.

IS4710 - Qualitative Methods. This research-seminar course has integrated the results of the FY05 Dillard-Nissen research into the students' course project.

Dillard, John T. "Centralized Control of Defense Acquisition Programs." IAMOT 2004 - New Directions in Technology Management: Changing Collaboration between Government, Industry and University. 3 -7 April 2004.

Dillard, John T. "Centralized Control of Defense Acquisition Programs: A Comparative Review of the Framework from 1987-2003." BPP Research Colloquium. 25 November 2003.

Copies of the Acquisition Sponsored Research Reports may be printed from our website www.nps.navy.mil/gsbpp/acqn/publications

ACQUISITION RESEARCH PROGRAM
GRADUATE SCHOOL OF BUSINESS & PUBLIC POLICY
NAVAL POSTGRADUATE SCHOOL
555 DYER ROAD, INGERSOLL HALL
MONTEREY, CALIFORNIA 93943

www.nps.navy.mil/gsbpp/acqn